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PHYSICAL FITNESS AS IT PERTAINS TO SUSTAINED MILITARY OPERATIONS

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EXECUTIVE SUMMARY

- With the development of the technical ability to maintain almost the same level of combat intensity during the twilight and nighttime hours as during daylight, it appears that combat in the future may require NATO units to perform continuous, high-intensity operations for periods exceeding 48 hours.
- One of the major effects of such continuous operations will be the loss of sleep which leads to decrements in human performance.
- This chapter considers two general elements of human combat performance: physical performance, and mental performance; and explores the relationship of physical fitness to each.
- Sustained performance of physical tasks is affected by physiologic parameters related to the supply of nutrients and removal of metabolic waste, sleep deprivation, time of day, transit across time zones, and environmental factors.
- Existing literature suggests that sleep deprivation does not affect maximal aerobic power, may affect muscle strength and endurance, does not impair well-learned, gross motor tasks, but does lead to deterioration of the speed with which coordinated hand and arm movements can be made.
- It appears that there is circadian variation in physical fitness parameters, and in physical work capacity. The magnitude of these effects appears to be small, and it is unclear that they will play a major role in performance under wartime conditions, where the motivation to survive will, presumably, allow one to overcome time-of-day effects of these parameters.
- It appears that aerobic capacity, and leg strength and endurance are unaffected by transit across time zones. However, arm strength and endurance appear to decrease.

- There is no evidence to indicate that increased physical fitness affects one's ability to adapt to time zone changes, or that fitness modifies circadian variation in physical performance.
- In general, the range of temperatures which can be tolerated decreases as the time of exposure increases.
- The use of protective clothing such as NBC clothing also impacts on the ability to sustain military operations. Protective clothing adds weight to the heavy combat load of the soldier. In addition, the clothing will impose a heat stress which will reduce operational effectiveness.
- Exposure at altitudes above 1,500 m leads to decrements in physical work. Investigations by Young, Cymerman, and Burse (1985) suggest that decrements in VO2 max on ascent to altitude are a function of sea level VO2 max values.
- Individuals with greater aerobic capacities show greater decrements in VO2 max with ascent to altitude.
- Physical fitness does impact on one's ability to tolerate heat. Whether or not physical fitness affects tolerance to the cold is difficult to assess.
- Recovery from physical exertion requires: 1) replenishment of the energy stores used to fuel the physical activity; and 2) repair of tissue damage sustained as a result of the physical activity. Replenishment of energy stores is complete within 24 hours, but repair of muscle damage may take up to 7 days.
- The rate at which one can perform work in a continuous fashion appears to be a function of one's maximal capability. Thus, the more fit one is the higher rate of work one will be able to sustain.
- Fitness levels can be modified by training or by the use of ergogenic aids. Because information relating to use of ergogenic aids is ususally available

only from athletic performance, its application to military operations is often questionable. It appears that a reported influence of caffeine upon work performance is controversial. It also appears that the use of carbohydrate loading programs, dietary modifications, and blood cell infusions offer the promise of improved physical performance during sustained operations. However, much work needs to be done to clarify the gains and costs of each technique and to adapt such techniques to the military setting.

- It is jobs which have a high cognitive load which have shown themselves to be greatly affected by sleep deprivation.
- Sleep deprivation effects interact with normal circadian variation so that rather than a continually decreasing level of performance, one finds rapid decreases in mental performance, usually from 0300 hours to 0600 hours followed by a plateau in performance at a lower level which is maintained throughout most of the day.
- The best way to maintain performance effectiveness during sustained operations is to provide sleep.
- While the ability to continue with physical work appears maintainable with 4 hours or less sleep, 4 hours sleep in each 24 is not sufficient to maintain cognitive functioning.
- The critical level of degradation appears after 3-4 days when a 4-hour nap is provided.
- It appears that increased physical work increases the frequency of occurrence lapses in attention.
- It appears that any effects of aerobic fitness on the rate of degradation of cognitive performance with sleep deprivation are small, but there is still a need for research which specifically addresses this question.

1. INTRODUCTION

1.1 Nature of sustained operations.

With the development of the technical ability to maintain almost the same level of combat intensity during the twilight and nighttime hours as during daylight, it appears that combat in the future may require NATO units to perform continuous, high-intensity operations for periods **exceeding 48 hours**. Such operations may be preceeded by a rapid deployment across several time zones, and may take place in extreme environments. One of the major effects of such continuous operations will be the loss of sleep which leads to decrements in human performance. This chapter will consider two general elements of human performance which are a part of combat: physical performance, and mental performance, and explore the relationship of physical fitness to each.

The conduct of war has many physical demands. These include the handling and movement of stores and munitions, the activity associated with the establishment of fortified positions (including trenching and mine-laying), and perhaps now to a lesser extent, marching over the ground carrying weapons and gear. The ability to continue intense physical work is limited by a variety of physiological and psychological factors. The decrement in the capacity to perform physical labor is called fatigue. This chapter will consider some of the factors which limit the ability to continue to perform physical activity.

Warfare has become increasingly technological in scope. The increase in

technology has increased the cognitive demands. With the development of faster, more sophisticated weapons, new sensor systems, command, control, and communications networks, today's military tactician or commander must be able to process greater volumes of information and arrive at tactical decisions more rapidly than ever before. This increased reliance on information processing and decision making is an important consideration here because it is these functions which degrade most rapidly in the face of sleep deprivation. This chapter will also explore evidence for interactions between physical fitness and degradation of cognitive performance.

2. SUSTAINED PHYSICAL PERFORMANCE

Sustained performance of physical tasks is affected by physiologic parameters related to the supply of nutrients and removal of metabolic waste, sleep deprivation, time of day, transit across time zones, and environmental factors.

2.1 Physiologic limitations to physical performance.

The period over which one can sustain physical work is determined by the rate of doing work. The more intensely one works, the more rapidly one becomes fatigued. The factors which are associated with exhaustion also vary with work rate. For work rates which can only be maintained for 15 minutes or less, fatigue is related to depletion of ATP, and CP stores (see Chapter 3) in the muscle, and the accumulation of hydrogen ions in the muscle cells as a result of lactic acid formation (Simonson, 1971, chapt. 1; Karlsson, 1979; Hermansen, 1981). For work rates leading to exhaustion in 1-6 hours, fatigue

seems to be related to exhaustion of intramuscular glycogen stores, although other factors such as dehydration due to thermal stress, ion shifts between body compartments, or depletion of metabolic substrate in other compartments (for example, depressed extracellular glucose) may also be important (Karlsson, 1979; Costill, 1974; Gibson and Edwards, 1985). When work is continued beyond 5 or 6 hours, fatigue appears to be related to shortage of fuels, particularly carbohydrate, in the muscles, plasma, or even in the liver, shifts in metabolic hormone levels (Simonson, 1971, chapter 2; Karlsson, 1979; Gibson and Edwards, 1985), and intracellular damage to muscles as a result of physical activity (Salminen, 1985).

Various authors have estimated the rate at which work can be continued for long periods of time. Astrand (1960) reported that aerobic work can be continued for one work day (7 hours of work: 50 minutes work, 10 minutes rest, with one hour off for lunch) if the work rate is maintained at approximately 50% of the maximal rate of oxygen consumption (VO2 max). Continuance of work beyond one day would appear to require that the work rate be maintained somewhat below 50% VO2 max. In Astrand's experiments, VO2 and heart rate rose and the respiratory exchange ratio fell over the course of the work day. These changes are consistent with the development of fatigue (Simonson, 1971, chapt. 2). Studies by Hughes and Goldman (1970), and Soule and Goldman (1973) suggest undue fatigue is not encountered if the work rate is maintained near 40% of VO2 max. However, when allowed to select their own work rate, soldiers appear to work at less than this suggested 40% rate. In a study of French infantry soldiers marching an average of 34 km per day for 6 day, Myles and his co-workers (1981) found that soldiers tended to select a marching pace which required an energy expenditure rate equal to 31.6% of VO2

max.

Data from the U.S. Army suggests the average soldier has a VO2 max equal to 53 ml/kg-min. Using the 70 kg man as our model and 40% VO2 max as our energy expenditure rate over several days, the average U.S. soldier could perform continuously (with some rest pauses) at an energy expenditure rate of 21.2 ml/kg-min or 7.2 kcal/min. Carrying a 25 kg pack, this average soldier could maintain a pace of 5.8 km/hr along a blacktop road, 5.3 km/hr through light brush, or 4.8 km/hr through heavy brush (estimated from Pandolf, Givoni, and Goldman, 1977).

Some have suggested that continuance of materials-handling tasks, such as lifting, is limited by maximal aerobic power. Fatigue does not appear to occur in men [Petrofsky and Lind (1978)] and women [Williams, Petrofsky and Lind (1982)], over the course of one hour if the work rate is maintained at less than 40% of VO2 max. However, inspection of their results suggests an interaction of weight lifted and lifting rate on the development of fatigue at a given VO2. For example, in the study reported by Petrofsky and Lind, lifting a 22.73 kg box at a rate sufficient to require 30 or 40% of VO2 max led to no rise in arterial lactate concentration, while lifting a 36.36 kg box at a rate requiring 25% VO2 max resulted in elevated lactate levels over one hour. In both studies, endurance time for isometric forearm contraction was decreased following one hour of lifting at all VO2 levels.

An interaction between the weight lifted and the rate of lifting has also been shown by Legg and Pateman (1985) in their study of maximal repetitive lifting capacities of British soldiers. Plots of time to exhaustion versus percentage

of VO2 max required for lifts of 25%, 50%, and 75% of maximal lifting capacity at three different energy expenditure levels, fails to give a single curve. There are instead, three different curves, one for each relative weight lifted. Thus limitations to lifting performance do not appear to be determined simply by aerobic power. Other variables need to be taken into account.

Monod (1985) has suggested that limitations to materials handling are imposed by strength and maintenance of adequate blood flow to the working muscles. He finds limitations to repeated lifting to be directly related to an individual's maximal voluntary contraction (MVC) force. In addition, contraction of muscles decreases the blood flow to that muscle, limiting the energy supply and allowing waste products to accumulate. Thus, the weight which can be lifted repeatedly depends upon the proportion of time that the muscle is contracted (and the blood supply is interrupted). Monod states that a critical fraction (between 15 and 20%) of MVC force can be maintained virtually indefinitely without local fatigue developing. Forces above this critical value can only be maintained on an intermittant basis. If the ratio of contraction time to relaxation time is 0.8, only 22% of the MVC force can be maintained without development of local fatigue. If the work/rest ratio is 0.3, static forces of 58% of MVC can be exerted without local exhaustion.

These sorts of data are in agreement with principles spelled out by Rowell. For work involving more than 50% of the muscle mass, it is the cardiovascular system which limits oxygen delivery to the working muscles. In these cases, measured VO2 max is a good indicator of work capacity. For work which involves less of the musculature, the rate of oxygen uptake by the muscles

appears to limit performance. In these instances, measures of muscle function or metabolism such as maximal strength, submaximal endurance time, or lactate production at submaximal loads become better indicators of performance potential.

2.2 Sleep deprivation effects.

Existing literature suggests that sleep deprivation does not affect maximal aerobic power, may affect muscle strength and endurance, does not impair well-learned gross motor tasks, but does lead to deterioration of the speed with which coordinated nand and arm movements can be made.

Takeuchi and co-workers (1985) tested muscular performance prior to and following 64 hours of sleep deprivation. They found no change in 40 m dash time, isometric handgrip force, balance, or isokinetic peak torque for knee extension or flexion at 180^{o}/sec as a result of the sleep deprivation. Vertical jump height was decreased as was isokinetic peak torque for knee flexion and extension at 60^{o}/sec.

Martin and Gaddis (1981) found no changes in rate of oxygen uptake, carbon dioxide production, ventilation, heart rate, or mean arterial blood pressure at 25, 50 or 75% of VO2 max following 30 hours of sleep deprivation. They also found VO2 max to be unchanged, but heart rate at VO2 max was depressed and perceived exertion was increased at 50 and 75% of VO2 max relative to normal sleep control.

Despite the apparent lack of effect on VO2 max due to sleep deprivation, it

does appear the physical work capacity may be affected. Martin and Chen (1982) found that time to exhaustion walking on a treadmill at 80% of VO2 max was reduced by 20% following a 50-hour sleepless period. This performance decrement occurred despite the finding of no difference between control and sleep-loss values for heart rate, plasma norepinephrine, epinephrine, and dopamine after 12 minutes of exercise, or ventilation, oxygen uptake, blood lactate levels, and rectal and skin temperature responses to the exercise. In addition, subjects were provided with monetary incentives which were increased for the sleep-loss trial. The authors conclude that the sympathoadrenal respose to exercise is intact following the period of sleep loss and that the decrease in exercise tolerance may occur due to nonphysiologic factors. However, Vondra and co-workers (1981) suggest that sleep deprivation leads to depletion of glycogen stores. If this is true, the decrease in muscle glycogen could account for the performance decrement found by Martin and Chen (see Clark and Conlee, 1979).

Turning to studies involving military personnel under simulated battle-field conditions, Haslam (1977) studied performance of 3 groups of British soldiers over a 9-day field trial (Early Call I). One group was given no sleep during the trial, a second group was given 1.5 hours of sleep each night, and a third group was given 3 hours of sleep each night. She measured the isometric strength for back flexion and extension, left and right forearm extension and flexion, leg extension, and handgrip. There was a general tendency for these strength values to decrease over the course of the trial. Exceptions were back flexion and handgrip, which increased. Estimates of stamina from bicycle work using the Astrand-Rhyming nomogram indicated a rise in stamina over the course of the trial. This effect is more likely due to a change in the

relationship between heart rate and VO2 resulting from participation in the trial than a change in fitness (Martin and Gaddis, 1981).

In a second study (Early Call II), Haslam (1978) studied 10 soldiers on a field trial in which they were given no sleep for 90 hours then 4 hours sleep in each 24 hours for the next 6 days. Measurements of isometric strength taken prior to and following the trial showed no change. Estimates of VO2 max from a 4-stage bicycle test also showed no change.

Handgrip strength in particular appears immune to sleep deprivation effects. Englund, et al., (1983) in studies of the effects of two successive 20-hour continuous work sessions separated by 3 hours of rest or nap found no change or improvement in handgrip strength over the course of the continuous work sessions. Keys and his co-workers in 1945 found no change in handgrip strength in 12 conscientious objectors following 62 hours of sleep deprivation (op. cit., Simonson, pg 437).

In a recent study of U.S. Army soldiers engaged in a 5-day field trial during which they were given 4-5 hours sleep in each 24 hours, Vogel and his colleagues (Vogel et al., 1983, Murphy et al., 1985) measured initial VO2 max, and 2-mile run time, anaerobic power of the arms and legs, and isokinetic strength for extension of the arms and legs prior to and following the trial. In addition, heart rates were recorded throughout the trial, and troop performance was evaluated by observers. Vogel and his co-workers found arm strength and arm anaerobic power to decrease following the field trial. Leg power did not change, and leg strength decreased for one isokinetic speed (30 deg/sec) but not the other (180 deg/sec). Two-mile run time increased

following the trial, but heart rates recorded during the run were less, leading to speculation that the soldiers may not have "pushed" as hard on the post-trial run. The average 24-hour energy expenditure level was 3.52 kcal/min (equivalent to an average VO2 of 10.0 ml/kg-min, or 18.7% of VO2 max for these soldiers). VO2 max was not, therefore, considered to be limiting, and inital VO2 max values were not correlated significantly with field performance (r=0.36 0.43).

In an 8-day military field artillery trial, Legg and Patton (unpublished manuscript) studied the effects of sustained, manual materials handling on 25 British soldiers. The trial simulated a real combat scenario and involved frequent moves of gun position, digging of defensive positions, preparation of camouflage, meal preparation, and simulated defense from infantry ground attack. Measurements of isometric, handgrip strength and upper and lower body anaerobic power (using the Wingate test) were made on two groups of soldiers: an experimental group which prepared, handled, and loaded artillery shells and charges weighing 45 and 13 kg, respectively; and a control group whose activities were the same as those of the experimental group except that they did not handle the shells and charges, but rather simulated the movements of preparing and loading the guns. The soldiers were allowed to get sleep as they could, and they averaged about 3.2 hours per day.

In contrast to most other studies, Legg and Patton found isometric handgrip strength to decrease continuously over the course of the field trial. There was no difference in decrement between the groups. It would not appear that this decrement is a function of handling the artillery shells.

Upper body anaerobic power (indicated as mean power output on the Wingate test) decreased for members of the experimental group, but not for members of the control group. This decrease in upper-body power, then, appears to be associated with continual handling of the artillery shells. Surprisingly, lower-body peak power and mean power were increased from pre-trial to post-trial. The reason for this finding is unclear. Perhaps it represents a selective fatigue of the slow-twitch fibers as a result of the sustained activity. While the lower-body, peak power and mean power did not differ between the study groups, the decrease in power during the test was greater for the experimental group, suggesting greater leg fatigue in this group than in the controls.

When one reviews the studies presented above, it becomes clear that most of the variation between studies relates to different findings for changes in strength measures. In the various studies presented, it is not clear whether these measured changes in strength actually represent changes in muscle physiology. While it is true that prolonged work can lead to histological changes reflecting damage to muscle and, perhaps, functional impairment (Salminen, 1985), indirect tests of muscle function, such as the voluntary maximal force tests used in the studies described above, require motivation on the part of the subject to perform maximally. Sleep deprivation is known to decrease motivation to perform many physical and cognitive tests (Colquhoun, 1981). In the absence of histological, biochemical, or electromyographic measurements, strength measures, by themselves, do not prove changes in muscle function. One must be careful in evaluating performance results in sleep deprivation studies. Without sufficient motivation to perform, physical performance variables may reflect subject temperament rather than physiology

(see Colquhoun, 1981; and Kleinhanss and Schaad, 1983 for a discussion of this point).

In summary: Sleep deprivation seems to have no effect on aerobic capacity. Furthermore, while muscle strength and power may decrease with sleep loss, it is not clear that sleep deprivation leads to physiological changes in the muscles which are responsible for measured strength changes.

2.3 Circadian effects on physical performance.

There are cyclical variations in physiological and psychological functions over the course of a normal day. These rhythms are known as circadian rhythms and persist despite a lack of cyclical variation in the environment, indicating they are an innate part of biological organization. Many aspects of human performance oscillate throughout the day, reflecting our circadian organization (Colquhoun, 1981).

When measurements are made of variations in aerobic fitness parameters over the course of the day, the following general findings emerge: Maximal aerobic capacity and maximal exercise heart rate appear to be invariant with time of day (Klein and Wegmann, 1980; Faria and Drummond, 1982). However, there are variations in the heart-rate response to submaximal exercise. The heart rate achieved at submaximal loads is less during the nighttime hours than during the day. The rate of oxygen consumption for submaximal work also differs with time of day, but the direction of the deviation depends upon the work load. When one compares the regression of oxygen consumption rate on work load computed for work performed at 0400 hours (nighttime) with that computed for

work performed at 1600 hours (daytime), one finds the slope of the daytime regression to be greater that the slope of the nighttime regression, but the intercept of the daytime regression is less than that of the nighttime regression. Thus, at work loads below 14-16 kpm/s night-time oxygen consumption is less than that observed during the daylight hours. At work loads above 14-16 kpm/s, the night-time rate of oxygen consumption exceeds the daytime rate (by about 4.6% at 27 kpm/min; Klein and Wegman, 1980).

Physical work capacity also shows time-of-day effects. Athletic performance has been shown to be better between 1600 and 1800 hours than between 0700 and 0800 hours (Conroy and O'Brien, 1973; Rodahl, et al., 1976). Physical work capacity measured as time to exhaustion on a bicycle ergometer work test has also been shown to be less during the nighttime hours than during the day (Weddige, 1974; Ilmarinen et al., 1975). The reasons for this decreased performance are unclear. However, work with rats by Clark and Conlee (1979) has shown a circadian variation in the amount of glycogen stored in the liver and muscles. The liver glycogen levels were 50% lower at 1900 hours than at 0700 hours, and the muscle glycogen levels lower by 16% - 50% at 1900 hours than at 0700 hours, depending on the muscle fiber type. Clark and Conlee also found that swimming-time-to-exhaustion for these animals was 39% less at 1900 than at 0700, suggesting a relationship between the amount of glycogen stored and endurance time. These findings have not been replicated with humans.

There appears to be very little information concerning variation in muscle strength and muscle endurance parameters with time of day. Ilmarinen and his co-workers (1980) found a significant circadian variation in handgrip strength ($\pm$4.2% of mean strength) with maximum grip strength at about 1200. Elbow

flexion strength has also been found to show circadian variation (6.9%, peak about 1800; Freivaldis, 1979). Ilmarinen, et al., (1980) also found a significant circadian rhythm in balance. The number of times an individual allowed a beam balanced on a pivot point to touch the ground showed a diurnal variation of ±21.7% about the mean value. Peak performance of the fitted cosine rhythm in balance was estimated to occur at about 1200.

Klein and Wegmann (1980) in their summary of circadian differences in human performance also report periodic oscillations in resistance to environmental stressors. During altitude chamber rides, the frequency of decompression sickness symptoms was reported to be 41% for subjects tested between 0900 and 1200 hours, but only 29% for subjects tested bewtween 1300 and 1600 hours. Klein and Wegmann (1980, p.15) suggest this difference in frequency of symptoms is associated with an increase in peripheral blood flow during the afternoon. Klein and Wegmann (1980) also report circadian variation in orthostatic tolerance (tilt table), acceleration (+Gz) tolerance, (tolerance is greater during the waking hours than during the night), altitude/hypoxia tolerance (most tolerant during the nighttime hours), and tolerance to oxygen toxicity (again, with the greatest tolerance during the sleep phase of the daily cycle). These differences in tolerance need to be taken into account for pilots of high-peformance aircraft, divers, and troops operating at altitude during sustained operations.

In summary, it appears that there is some circadian variation in physical fitness parameters, and in physical work capacity. The magnitude of these effects appear to be small, and it is unclear that they will play a major role in performance under wartime conditions, where the motivation to survive will,

presumably, allow one to overcome time-of-day effects on these parameters.

2.4 Effects of time zone change.

When military personnel are transferred rapidly across several times zones, as in rapid deployment from the United States to Europe, there are two basic disruptions of normal functioning which occur. Firstly, the arriving personnel are out of synchrony with the sleep/rest cycle in the new environment, and performance may be compromised due to circadian variations described above. Secondly, personnel may suffer fatigue related to inadequate or disrupted sleep, or inactivity and discomfort associated with the travel itself. In studies of effects of translocation it is difficult to separate these effects.

Wright, et al., (1983) have studied the effects of travel across six time zones (from Texas in the United States to West Germany) on exercise capacity and exercise performance in eighty-one male soldiers. Comparison of results of aerobic capacity tests prior to departure and following translocation revealed no differences in maximal or submaximal rates of oxygen uptake, maximal or submaximal heart rate, maximal or submaximal ventilation, or maximal or submaximal perceptions of exertion. The perceived exertion findings were surprising since most of the soldiers reported subjective feeling of increased fatigue and sleepiness following the flight. Wright and his co-workers also found no systematic changes in isometric strength associated with the translocation. They did find that dynamic strength measured isokinetically was decreased 6.1% at 36 deg/sec and 10.8% at 180 deg/sec. Dynamic muscle endurance at 180 deg/sec was decreased as well with a

mean reduction in peak torque over 60 sec of work of 13.3% per contraction. Changes in leg dynamic strength were difficult to interpret as there was an effect of repeated testing which interferred with both pre- and post-translocation measurements.

Wright, et al., also measured performance on four field tests of physical ability: a 2.8-km run; a 270-m sprint; a 100-m fireman carry; and a 6-m rope climb. These were included to measure impact of translocation on the basic skills of running, climbing, and carrying. No differences in performance were seen in the run, carry, or rope climb. Analysis of changes in sprint performance revealed that one of three test groups had significantly increased sprint times following translocation. The other two groups showed non-significant increases in sprint time.

It would appear from these findings that aerobic capacity and leg strength and endurance are unaffected by transit across time zones. There appears to be a decrease in arm strength and endurance with translocation. The finding that rope-climb performance did not reflect this arm strength decrement is probably because the rope climb does not require maximal force output by the muscles and the task duration is too short to be effected by the decreased muscle endurance.

2.5 Effects of the environment.

The environment within which sustained operations must take place also influences physical performance.

2.5.1 Climate

NATO personnel may be required to fight in climates ranging from +42^{o}C to -48^{o}C. Above 0^{o}C, the limit of endurance is dependent on the ambient temperature, solar heat load, relative humidity, amount of physical activity and amount of clothing worn. As the body's ability to lose heat is decreased, the time of useful work also decreases.

In general, the range of temperatures which can be tolerated decrease as the time of exposure increases. Considering heat tolerance, 43^{o}C can be safely tolerated for 1 hour at 50% relative humidity; 34^{o}C can be safely tolerated for 1 day at the same humidity, and 31^{o}C can be tolerated for 10 days. At 100% relative humidity, these temperatures decrease to 35^{o}C, 29^{o}C, and 27^{o}C for 1 hour, 1 day, and 10 days, respectively (NATO Defense Research Group, 1981).

For cold-temperature tolerance, the lower limits are determined by clothing levels and physical work load. For a 1-hour period, the minimum, safely-tolerated, temperature ranges from -46^{o}C to -29^{o}C, depending upon clothing and work load. For 1 day, the range is -9^{o}C to +4^{o}C. For a 10-day period the range is -3^{o}C to +7^{o}C. One of the main factors limiting performance in the cold is the temperature of the hands and feet (Vanggaard, 1978). It is important that hand temperatures are kept above 15^{o}C otherwise dexterity and sense of touch are lost; when the skin temperature falls to 10^{o}C, pain is felt.

However, it appears that cold exposure may limit performance even when the

hands and feet are protected. In a chamber study of the effects of acute cold exposure on submaximal endurance performance, Patton and Vogel (1984) found that exposure to $-20^{\circ}C$ did not affect VO2 max measured on a bicycle ergometer, but that endurance time on the bicycle ergometer at approximately 78% of VO2 max decreased. The reason for decreased endurance time is not clear. A possible cause is early depletion of glycogen stores following a one day exposure to $-20^{\circ}C$. Jacobs and his co-workers (1984) find that low-level exercise at $9^{\circ}C$ results in a substantially greater increase in glycogen utilization than the same exercise at $21^{\circ}C$. Since the subjects in Patton and Vogel's experiments spent the night in the cold chamber prior to their endurance event, it is possible that muscle glycogen stores were partially depleted.

The use of protective clothing such as NBC clothing will also impact on the ability to sustain military operations. Protective clothing adds weight to the heavy combat load of the soldier, and hence, increases the amount of work necessary to perform tasks. In addition, the clothing will impose a heat stress which will reduce operational effectiveness. Adequate work/rest schedules to prevent excessive heat build up remain to be determined. Excessive sweating due to heat build up in the suits may cause medical problems from excess sweating and chafing of the skin by clothing.

Sleep deprivation may influence tolerance of climatic extremes. Work by Sawka and his co-workers (1984) has indicated that heat-adaptive responses are modified with continued sleep depriviation. In a study of responses to 40 minutes of exercise at 50% of VO2 max, these researchers found that 33 hours of wakefulness lead to decreases in evaporative and dry-heat loss, and a

greater rise in esophageal temperature. Thus sleep deprivation may decrease the ability to perform in the heat.

2.5.2 Altitude

Exposures to altitudes above 1,500 m leads to decrements in physical work. VO2 max is reported to decrease 10% for each 1000 m above 1500 m (Grover, 1979). These changes in aerobic capacity are reflected in a decreased work capacity when compared to sea level performance. Tasks must be performed at a proportionately lower work rate (compared to sea level) if performance is to be sustained.

2.6 Recovery from physical exertion.

Recovery from physical exertion requires: 1) replenishment of the energy stores used to fuel the physical activity; and 2) repair of tissue damage sustained as a result of the physical activity.

It was suggested earlier that the metabolic limits of performance depended on the rate of energy expenditure and that for exercise of different durations there were different limiting factors. The rate of "metabolic" recovery from physical exertion also depends upon the particular factor which was limiting to performance.

Recovery from short duration, high intensity exercise which results in exhaustion of the ATP and CP stores, takes only a matter of seconds. ATP and CP can be replenished anaerobically through glycolysis. So, all that is

required is to cease activity briefly to allow replenishment.

Recovery from high intensity exercise which results in accumulation of lactate in the muscles takes a matter of minutes. Recovery from lactic acid build up requires re-establishment of the blood supply to the muscles to allow aerobic metabolism of lactate to take place, or to wash the lactate out of the tissue for metabolism elsewhere in the body (Donovan and Brooks, 1983; Gibson and Edwards, 1985; Monod, 1985).

Recovery of muscle glycogen stores is generally complete within 24 hours when the individual is relatively sedentary and adequate carbohydrate is supplied. With continuously high work rates, it does not appear that muscle glycogen stores are replenished (Costill, et al., 1971). Therefore, some rest must be provided during periods of intense work to allow replenishment of these stores if the ability to perform intense work is to be maintained.

When physical work results in cellular damage to the muscle, the period of time required for recovery is somewhat longer than for replenishment of energy substrates. Salminen (1985) found that heavy physical exertion caused scattered necrotic injuries in muscle fibers and some inflammation of skeletal muscles of rats and mice. Repair of these injuries involved invasion by phagocytic cells with removal of debris and subsequent rebuilding of the fibers. The repair processes peaked about 3 days after a heavy exercise bout and complete repair required 5-7 days. The degree of cellular damage seen was related to the duration and intensity of the exercise. The repair responses to damage seemed to be decreased in older mice. It is unclear from these investigations whether or not the time course of repair changes with increased

damage. However, it would seem that the level of work that can be maintained increases with increased training or decreased work load.

In concert with the findings on cytological changes, one can observe changes in the blood concentration of hormones and enzymes related to muscle damage and repair. Stromme and his co-workers (1978) have reported CK and LD elevations which persisted for 3 days following a 90-km race and 2 days following a 70-km race. Similar elevations in CK and LDH have been reported by Hodgdon and his co-workers (1980) following a 24-km run by less endurance trained individuals. Demos and Gitin (1974) report elevations in the levels of these enzymes in cases of pathologic muscle damage. The time course for return to pre-injury levels was similar to that for the cytological indicators studied by Salminen. Pesquies and co-workers (1981) found that plasma testosterone values were increased following a 100-km footrace. Plasma testosterone was found still to be elevated 36 to 72 hours following the race. Increased testosterone, because of its role in promoting protein incorporation into cells, is thought to be indicative of repair in progress.

2.7 Impact of physical fitness.

As must be apparent from the discussion above, the rate at which one can perform work in a continuous fashion appears to be a function of one's maximal capability. While it is unclear from current research whether one can be expected to work continuously at 30% or 40% of VO2 max or 25% or 40% of one's maximal lifting capacity, it is clear that the more fit one is (either in terms of aerobic capacity or muscle strength and endurance) the higher rate of work one will be able to sustain. In addition, increased fitness decreases

the level of muscle damage incurred with strenuous physical work (Salminen, 1985), and increases the rate of recovery from short-term fatigue processes.

There is no evidence to indicate that increased physical fitness affects one's ability to adapt to time zone changes, or that fitness modifies circadian variation in physical performance. Physical fitness does impact on one's ability to tolerate heat. The more aerobically-fit individual has, in general, an increased heat tolerance. Whether or not physical fitness affects tolerance to the cold is difficult to assess. To the extent that different training programs may increase the muscle glycogen stores, they may improve endurance performance at low work loads (Jacobs et al., 1985). Investigations by Young, Cymerman, and Burse (1985) suggest that decrements in VO2 max on ascent to altitude are a function of sea level VO2 max values. In this instance, individuals with greater aerobic capacities show greater decrements in VO2 max with ascent to altitude. Aerobic fitness levels account for 31% of the variance in VO2 max decrement (r=0.56), indicating a great deal of additional variance to be accounted for.

Fitness levels can be modified by training or by the use of ergogenic aids such as diet/exercise manipulations or red blood cell infusions.

2.8 Ergogenic aids.

Performance in athletic competition has been shown to be increased by a variety of physiologic interventions. Such interventions are known as ergogenic aids because they allow greater work output rates. Ergogenic aids include diet and exercise modifications such as carbohydrate loading, body

fluid alterations, such as red blood cell infusions; and use of drugs, such as caffeine to increase the supply of fats to the working muscle (Strauss, 1984).

Because information relating to use of ergogenic aids is usually available only from athletic performance, its application to military operations is often questionable. Athletic competition requires performance near one's maximal capabilities. Military performance, for the most part, appears to require lower levels of physical performance.

2.8.1 Carbohydrate loading.

As indicated above, development of fatigue with long-distance, high-endurance, athletic events such as cross-country skiing and marathon running has been shown to be related to exhaustion of muscle glycogen stores. Carbohydrate loading is a technique involving manipultaion of diet and exercise patterns designed to increase muscle glycogen stores.

Carbohydrate loading consists of two steps: a depletion of muscle glycogen stores; and a subsequent super-replenishment of those stores. Depletion is accomplished by a period (usually two or three days) of intense exercise workouts accompanied by intake of a diet which is low in carbohydrate. This procedure depletes the muscle of its glycogen and stimulates the enzymes responsible for the synthesis of glycogen in the muscle. Repletion or "loading" is then accomplished by cutting back to light exercise workouts while consuming a diet which is high in carbohydrate. Because muscle enzyme activity has been enhanced, the excess carbohydrate in the diet results in the formation of greater than normal amounts of glycogen in the muscle cells.

With elevated muscle glycogen levels, the time required to exhaust the muscle glycogen will be increased.

Using U.S. Navy Special Forces personnel, Hodgdon and his co-workers (1978) have shown that following a carbohydrate loading program leads to a 9% increase in the time to exhaustion while running on a motor-driven treadmill at 75% of VO2 max when compared to exhaustion time following a mixed diet of normal composition. It is unlikely that the work load during sustained operations will be 75% of VO2 max for extended periods of time.

Guezennec (1983) has suggested a dietary approach to maintenance of optimum performance in commando forces that involves utilization of both high carbohydrate and high fat diets. High carbohydrate diets are consumed prior to missions and during periods of rest during missions to replenish muscle glycogen stores. High-fat diets are consumed during the active periods in a mission to decrease the rate of muscle glycogen utilization, thus sparing the glycogen stores for periods of intense physical effort.

Jacobs, and co-workers (1983), have shown muscle glycogen to decrease substantially in Swedish troops participating in 4.5 days of winter war games. The data presented by these researchers were not analysed to indicate whether initial glycogen levels influenced the amount of glycogen remaining after the 4.5 day period, but the possiblility exists that carbohydrate loading might be useful preparation for sustained operations, particularily in the cold.

2.8.2 Blood doping.

Blood doping, the infusion of red blood cells into the vascular space to increase the oxygen carrying capacity of the blood, has been shown to be an effective way of increasing maximal aerobic capacity and endurance performance (Hodgdon and Campbell, 1982; Kanstrup and Ekblom, 1984). To be effective, it has been found that a red blood cell volume of at least 322 ml (either as whole blood, resuspended red blood cells, or packed red blood cells) must be infused, and the packed cell volume at the time of infusion must be in the normal range (Hodgdon and Campbell, 1982). Hodgdon and his co-workers (1982) have shown that following such a program, VO2 max was increased 11.7% with a proportionate increase in the VO2 at the lactate accumulation point. In this study, 3-mile run time was decreased by 8 sec/mile. Bearing in mind that increased aerobic capacity ought to be related to an increase in the rate of performance of endurance tasks, these findings suggest that blood doping may have potential for extending work capacity under sustained operations. Unlike many other fitness augmentation techniques, the effects of RBC infusion are rather long-lived, the half-life of a red blood cell being on the order of 120 days. However, the need to keep a supply of properly matched blood on hand for use prior to engaging in sustained activity may limit the usefulness of this particular technique for military operations.

2.8.3 Caffeine.

Caffeine and other methylated xanthines (theophylline, found with caffeine in tea; and theobromine, found with caffeine in chocolate and cocoa) have been suggested to be effective ergogenic aids. The basis for this belief are the

findings of Costill, et al., (1978), Essig and co-workers (1980), and Powers, et al., (1983), that caffeine increases the breakdown of fats in the adipose tissue and results in increased free fatty acid levels in the blood. This increased mobilization of free fatty acids allows fats to contribute a greater proportion of the energy supply for work, and thus, allows the muscle glycogen stores to be spared. Glycogen sparing should extend endurance performance by postponing the exhaustion of muscle glycogen stores. Costill and his co-workers (1978) have, in fact, shown increased performance time at 80% of VO2 max on the cycle ergometer. Essig and co-workers concluded that ingestion of caffeine decreased muscle glycogen utilization by 42% during prolonged work.

However, in a recent review of the effects of caffeine on endurance performance, Powers and Leon (1985) indicate that previous work has failed to systematically take into account the fitness of the subjects, the level of tolerance to caffeine, and the mode of exercise. Based on their review and the findings of Casal and Leon (1985), one would conclude that caffeine has little or no effect on highly endurance trained individuals since their muscles are already adapted for maximal fat uptake and utilization, or individuals with a high tolerance to caffeine since these individuals have a decreased response to caffeine ingestion. A rather surprising finding is that while caffeine does appear to enhance performance on the cycle ergometer it appears to have little effect on running performance (Casal and Leon, 1985). Knapik and his co-workers have suggested that this differential augmentation of performance may result because cycling involves a smaller active muscle mass. It is thought that utilization of a smaller muscle mass results in a greater flux (per unit of muscle mass) of fatty acids through the vasculature

perfusing the active muscles.

Thus it would appear that the influence of caffeine upon work performance is controversial. Perhaps its main benefit still lies in its stimulation of mental processes.

2.8.4 Summary

It would appear that the use of ergogenic aids offer the promise of improved physical performance during sustained operations. However, much work needs to be done to clarify the gains and costs of each technique and to adapt such techniques to the military setting.

3. SUSTAINED COGNITIVE PERFORMANCE

Not all of the jobs envisioned in future combat scenarios require physical activity. Tactical coordination center jobs consist largely of monitoring visual displays for information, monitoring audio presentation of messages, synthesis of gathered information, and making of tactical decisions. It is jobs such as these which have a high cognitive load which have shown themselves to be greatly affected by sleep deprivation.

3.1 Factors affecting sustained cognitive performance.

Numerous studies have documented the effect of sleep deprivation on cognitive, quasi-military tasks. Johnson (1982), in a review of sleep deprivation and performance points out that in the evalution of performance following periods

of sleep loss, one must focus not so much on the emitted responses, but rather on the absence of responses. It appear that a principal feature of sleep loss is the appearance of periods of inattention. As sleep loss increases, performance becomes more and more uneven, with efficient behavior alternating with faltering responses or no responses at all. With increasing task duration, one is more apt to see errors of omission. However, accuracy of performance seems to depend upon whether the task is self-paced or work paced. If the task is a self-paced one such as encoding or decoding, with increasing sleep deprivation, speed will be impaired but accuracy will remain high. In work-paced tasks such as watching a radar screen or monitoring radio communications, the occurrence of periods of inattention will lead to errors of omission, and missed information. Errors of omission will also increase as the work load increases since the time allowed for response will decrease.

As is the case with physical performance, there is circadian variation in cognitive tasks. Sleep deprivation effects interact with normal circadian variation so that rather than a continually decreasing level of performance, one finds rapid decreases in mental peformance, usually from 0300 hours to 0600 hours followed by a plateau in performance at a lower level which is maintained throughout most of the day.

3.2 Recovery from cognitive fatigue.

The best way to maintain performance effectiveness during sustained operations is to provide sleep. The question is "how much?". Work by Haslam (1978) and by Vogel and co-workers has suggested that physical performance can be continued for 9 days on 4 hours of sleep in each 24 hours. Haslam (1977)

found that British soldiers remained effective in the field on physical tasks for 3 days with no scheduled sleep, for 3-6 days on 1.5 hours sleep, and for 9 days (the duration of the study) with 3 hours sleep. The main effect of sleep deprivation was deterioration of mental ability and mood. Opstad and his co-workers (1978) have shown that physical performance can be continued with some decrements with a total of 3-6 hours composed of naps or micro-sleep over a period of 92-120 hours of continuous training. However, while the ability to continue with physical work appears maintainable with 4 hours or less sleep, work summarized by Naitoh and his associates indicates that 4 hours sleep in each 24 is not sufficient to maintain cognitive functioning. Job performance may be satisfactory for several days, but performance will degrade with successive days. The critical level of degradation (and hence, time of useful performance) will vary from task to task, but appears to be 3-4 days with a 4-hour nap. Naitoh and his associates have concluded that the timing of naps is not critical.

3.3 Impact of physical fitness.

Studies which relate to the question of interrelationships between physical fitness and decrements in cognitive performance take two forms: (1) studies of the effects of physical work on cognitive performance, and (2) studies of the effect of fitness levels on cognitive performance. Several investigators have looked at the effect of doing physical work on the rate of decrement in cognitive performance. Lubin and his co-workers (1976) reported the performance of bicycle exercise to be associated with a decrease in performance on auditory vigilance and addition tasks over a 40-hour period when compared to a group given bed rest (but not sleep) for that period.

Angus and co-workers (1985) looked at changes in performance over 64 hours of sleep deprivation in two groups: one which walked on a treadmill at 25-30% of VO2 max for one hour in every three, and one which was given no exercise for that hour. Both groups performed cognitive tasks during the remaining time. No differences between groups were found for fatigue and sleepiness ratings, moods, vigilance, or percent correct in serial reaction time. However, the number of "gaps" (reaction times exceeding 1 sec) recorded during the serial reaction time test was significantly higher in the exercising group.

Similar results were found by Naitoh and his co-workers (reported by Hodgdon et al, 1983). In this study, two groups of U.S. Marine Corps volunteers were subjected to two 20-hour continuous work episodes separated by 5 hours which included a 3-hour nap. One group exercised on a treadmill at approximately 30% of VO2 max for one half hour out of each hour. A variety of cognitive tasks of varying levels of complexity were administered. Significant exercise effects were found only for serial reaction time and four-choice reaction time, and then only when the response omission scores were included in the mean reaction time.

In the studies of Angus and associates and of Hodgdon and co-workers, the work load was set relative to the subject's aerobic fitness level. It is, therefore, impossible to assess the impact of fitness levels on subject response. However, it does appear that physical work effects the frequency of occurrence of periods of inattention.

One can argue that since performance decrements at 17% of VO2 max (the approximate overall work load for the exercising groups in these studies) were

greater than decrements at work loads of 10% of VO2 max or so for the non-exercising groups, that increased aerobic fitness levels might offer some protection from the effects of sleep deprivation. However, with the small differences in effects seen and the small differences in energy expenditure levels present in these experiments, such a conclusion is extremely tenuous. What is needed is studies which look at the effects of fitness directly.

To date, such studies have been inconclusive. Investigators in this area have been unable to obtain subjects who were matched on non-fitness variables, or subjects who were able to complete imposed work loads greater than 30% VO2 max.

It appears that any effects of aerobic fitness on the rate of degradation of cognitive performance with sleep deprivation are small, but here is still a need for research which specifically addresses this question.

4. CONCLUSIONS

It appears that the level of physical fitness is related to the physical work rate that can be maintained nearly continuously. This is the case whether the work rate is limited by cardiovascular-respiratory capacity or muscle physiology. Determination of required levels of fitness for sustaining military operations awaits suitable detailing and physiological measurement during realistic combat scenarios.

Physical fitness has not been directly linked to changes in the rate of degradation of cognitive performance under conditions of sleep deprivation.

One can infer protective effects of increased aerobic fitness on decrements in cognitive performance, but such effects are small, and of questionable importance. There remains a need for studies which allow direct evaluation of the impact of physical fitness.

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13. ABSTRACT *(Maximum 200 words)*

With the development of the technical ability to maintain almost the same level of combat intensity during the twilight and nighttime hours as during daylight, it appears that combat in the future may require NATO units to perform continuous, high-intensity operations for periods exceeding 48 hours. One of the major effects will be the loss of sleep which leads to decrements in human performance. This chapter considers two general elements of human combat performance, physical performance and mental performance, and explores the relationship of physical fitness to each. Existing literature suggests that sleep deprivation does not affect maximal aerobic power, may affect muscle strength and endurance, does not impair well-learned, gross motor tasks, but does lead to deterioration of the speed with which coordinated hand and are movements can be made.

It appears that the physical work rate that can be maintained nearly continuously is related to level of physical fitness. This is the case whether the work rate is limited by the cardiovascular respiratory capacity or muscle physiology. Determination of required levels of fitness for sustaining military

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operations awaits suitable detailing and physiological measurement during realistic combat scenarios.

Physical fitness has not been directly linked to changes in the rate of degradation of cognitive performance under conditions of sleep deprivation. One can infer protective effects of increased aerobic fitness on decrements in cognitive performance, but such effects are small and of questionable importance. There remains a need for studies that allow direct evaluation of the impact of physical fitness.